Practices to Increase Wheat Grain Protein

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EB0206
Revised March 2025

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To produce high grain protein there must first be enough nutrient resources to meet wheat's requirements for vegetative growth and grain yield. Then, if available nitrogen (N) and N uptake satisfy growth and yield requirements, extra N taken up is used for increasing grain protein. Grain from wheat stressed by drought or high temperatures during grain fill frequently has higher protein, though certain crop and fertilizer management practices can increase protein without sacrificing yield, regardless of weather conditions.

Low grain protein is a financial loss to producers, especially in years with high protein discounts and premiums. On average, dryland spring wheat grown in Montana requires 3.3 lb available N/bu to reach 14 percent protein, where available N = soil N + fertilizer N (*FF17*, see 'Fertilizer Facts' on page 11). Based on a survey by Jones (unpub. data), Montana producers use an average of 2.6 lb N/bu on spring wheat. When discounts are high, this under-fertilization could equate to potentially tens of millions of lost revenue dollars statewide. However, fertilizing at higher N rates could also increase rates of soil acidification. This bulletin provides information on factors and practices affecting protein of both spring and winter wheat.

Process of making grain protein

Nitrogen is a basic component of amino acids which are the building blocks of protein necessary for plant growth. Protein is stored in the grain for seedling success. Nitrogen taken up before heading generally increases yield if other resources, such as water, phosphorus and potassium, are not limiting. If N is very deficient, grain protein content decreases with increasing yield due to a dilution effect (**Figure 1**). As N supply increases, both yield and protein increase. When yield reaches its maximum, additional N will continue to increase protein to a maximum level. Most of the N used by wheat for grain protein is taken up before heading or flowering and moved to the developing kernel during grain fill (*2*). However, N can still be taken up during and after heading. This N tends to increase protein, because generally by then yield potential has been determined (*3*, **Figure 2**, page 2).

However, if additional N fertilizer is not taken up by the crop it will likely lead to acidification (lowering of pH) of the top few inches of soil. This will ultimately cost producers through lost yields and/or the need for lime to restore soil pH. See Cropland Soil Acidification (under 'Web Resources' on page 9) for more information about this growing issue.

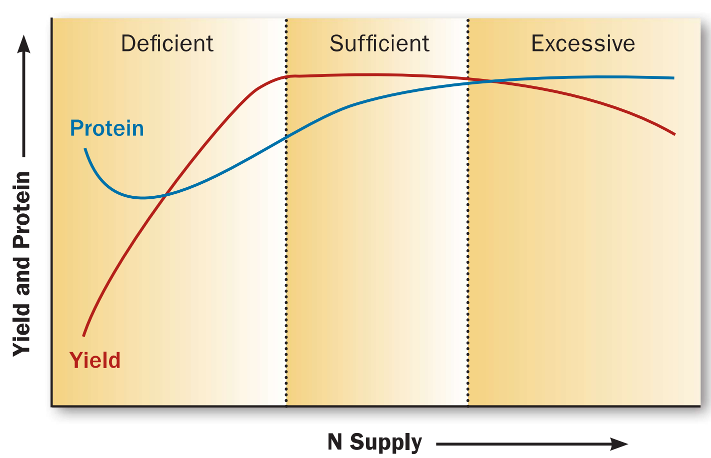

Figure 1. The response of wheat yield and grain protein to increasing N (*1*).

Practices to increase protein

CROP MANAGEMENT

Growing wheat with high grain protein begins with selecting the appropriate variety followed by management practices that increase N availability late in the season. Using cultural practices or adding other nutrients to increase yield without adding additional N can reduce rather than increase protein.

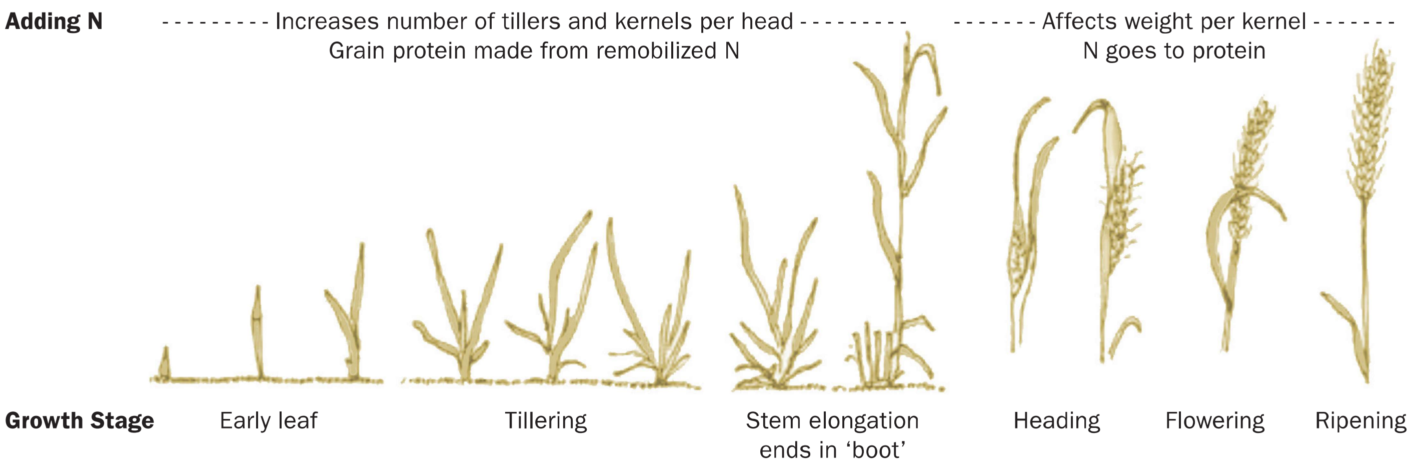

Figure 2. Approximate cereal growth stages and N application timing effects on yield and protein. This figure was modified from its original (*4*).

Variety

Low yield varieties tend to be higher in protein, and vice versa, with less N fertilizer. For example, based on 163 site-years of data in Montana, Rampart yielded 7.7 bu/acre less than CDC Falcon (53.2 vs 60.9 bu/ac), but was 1.0 percent point higher protein (13.4 vs 12.4 percent; *5*). Growers can use the MSU variety selection tool webpage (see 'Web Resources' on page 9) to help pick a high yielding, high protein variety based on the traits they desire, and their location and cropping system. Protein quality is a factor in wheat varieties grown for bread making. Practices that benefit protein content tend to also benefit protein quality, especially when total N uptake was low (*3, 6*).

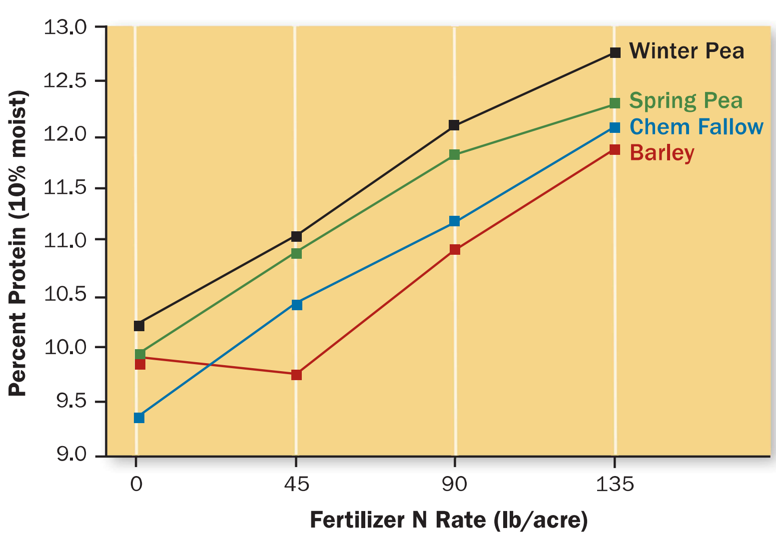

Figure 3. Winter wheat grain protein content when grown after chemical fallow, winter and spring pea grown for grain, and barley in Gallatin Valley, Montana (*7*).

Water

Drought-stressed wheat may have higher protein content because of lower yield. Even in irrigated systems, withholding water late-season generally increases protein. However, there are times when withholding late-season moisture can reduce N availability and uptake, which can reduce protein (*3*), and possibly test weight.

Rotations and Cultivation

In southwest Montana, dryland winter wheat consistently had higher protein when grown after winter and spring pea grown for grain than after fallow or barley (**Figure 3**). Legumes grown as green manure will contribute more N towards grain protein than legumes grown for hay or grain. In general, a legume green manure will fix more N the longer it is allowed to grow, especially in moist years. However, this must be balanced with its water use so the following crop yield is not reduced (*8*). Earlier termination retains more soil moisture and allows more time for the N to become available.

Reduced or no-till management may increase available moisture but reduces the rate that N becomes available from plant residue. In semi-arid regions of Saskatchewan with medium- and fine-textured soils, an additional 20 lb N/acre was required under no-till versus conventional till to produce acceptable grain protein in the first six years after conversion (*9*). These researchers concluded that no-till systems on medium- to fine-textured soils may require additional fertilizer N relative to tilled systems for at least 15 years after conversion to no-till. Less additional N may be required for fewer years in more coarse soils.

SOIL FERTILITY MANAGEMENT

Protein production requires sufficient amounts of several nutrients in addition to N such as sulfur and potassium. However, this bulletin focuses on N management.

Nitrogen

Providing adequate available N may be the most important management factor to produce high grain protein. The following points can help guide N management for high protein wheat without increasing the risk of soil acidification.

Base pre-plant N rates on realistic yield potential.
Applying high rates of N before or at seeding is risky, especially in dryland farming. If there is not enough rainfall, then the fertilizer may not produce additional yield or protein. In dryland production, early season N rates should be selected to limit excessive vegetative growth which could deplete soil moisture before flowering and grain fill. Based on studies throughout Montana, dryland winter wheat requires an average of 2.3 lb N/bu to produce 40 bu/acre with 12.5 percent protein, and spring wheat requires an average of 3.3 lb N/bu to produce 40 bu/acre with 14 percent protein when soil organic matter is 2 percent (Small Grains Nitrogen Economic Calculator under 'Web Resources' on page 9). In-season N fertilization can be used to adjust rates to increase yield and protein in a high yielding year. In irrigated production, applying all the N needed for yield and protein early in the season can produce more tillers than are able to produce grain. This excess vegetation can reduce yield. Also, when early-season N fertilization is excessive, late-season N applications are inefficiently used and can contribute to high residual soil nitrate levels.

Producers can evaluate the effectiveness of their N fertilization practices by looking at their past grain protein levels. If winter wheat protein is under 12.5 percent then yield and protein have likely been N limited. To gain 1 protein point (percent) in winter wheat would require approximately an additional 22 lb N/acre with less than 6 inches growing season precipitation or 33 lb N/acre with more than 12 inches growing season precipitation or irrigation (*FF34*). For spring wheat, grain protein under 13.2 percent indicates that yield and protein have been compromised by under-fertilization (*FF21*). The MSU Small Grains Nitrogen Economic Calculator is a resource to help predict grain protein and calculate economically optimum N rates based on available soil nitrate, soil organic matter, yield potential, wheat price, nitrogen price, and protein discount.

Know your soil residual N.
Use soil nitrate tests to calculate early season N application rates. Spring soil samples better reflect N available to a crop during the growing season than fall samples, especially on shallow soils with greater than 60 lb N/acre. In a three-year study at eight sites throughout Montana, 35 percent of the soil samples had lower nitrate in April than the previous November. Up to 60 lb N/acre was lost over winter on some sites, most likely to leaching (*10*), while other sites gained soil N overwinter. If spring fertilization rates are based on fall soil samples, the crop may be under- or over-fertilized. See Soil Sampling (under 'Web Resources' on page 9) for more information on soil sampling.

Test crop N status.
Determine whether a top-dress application has a good chance of increasing protein by measuring flag-leaf N concentration (uppermost leaf of the stem sampled at heading), chlorophyll (SPAD readings), or spectral indices from aerial imagery. Grain protein is likely to increase with late-season N if the flag-leaf N concentration is less than 4.2 percent (**Figure 4**). This critical flag-leaf N concentration goes down as the cost of N goes up and protein discount goes down. See The Soil Scoop *Nitrogen Management for Grain Protein* for examples of this relationship. Lower flag-leaf N concentrations indicate a higher potential response to late season N, but more N will be required to reach high protein. The amount of protein increase with late N relative to flag-leaf N varies with year (**Figure 4**) and may vary among

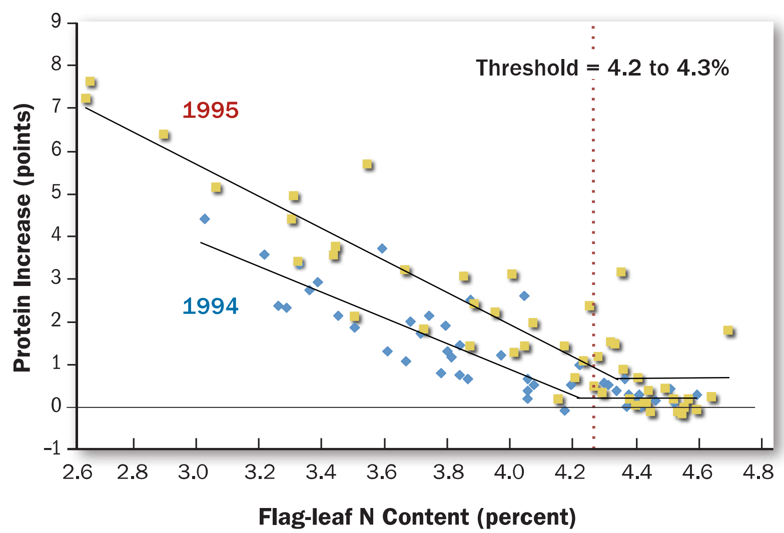

Figure 4. Irrigated spring wheat grain protein response to 40 lb N/acre top-dressed at heading for a range of flag-leaf N contents at flowering (*FF12*).

varieties (*FF23*). Protein response to top-dressing based on flag-leaf N tends to be more reliable in winter wheat than in spring wheat because many of the problems facing winter wheat occur prior to heading when the decision to top-dress is being considered. Also, there is a better chance for rain after winter wheat flowers than after spring wheat flowers, to push the N into the root zone. Flag-leaf analysis can tell you whether the crop is likely to increase protein content with late-season N, but not how much N to add or the final protein level (*FF12*).

Chlorophyll SPAD readings of irrigated spring wheat at heading that are less than about 93 to 95 percent of a well-fertilized reference plot indicate grain protein will likely respond to late-season N (*FF12*). However, SPAD readings are not a reliable tool to predict protein response in dryland winter wheat in our region (*FF23*). Aerial imagery can be used to determine patterns of N nutrition status across a field to make late-season variable rate N adjustments to increase grain protein (*11*).

Determine rate and timing.

Once N for yield is met, protein will increase proportionately with increasing N, at least up to 14 percent in spring wheat. Increasing protein above 14 percent may be more difficult (*3*). High yields will require more in-season N per acre to increase protein by a point than low yields; that is, the protein increase from a given amount of N is less for high than low yields. For example, on dryland winter wheat with 60 lb N/acre preplant, 30 lb N/acre top-dressed at tillering increased grain protein by 1.4, 0.5 and 0.1 points for 53, 76, and 89 bu/acre, respectively (*FF23*). There may be a limit to how much late-season N can be applied. An Idaho study found 75 lb/acre of late-season N on irrigated wheat increased lodging and reduced yield (*3*).

Timing N application close to maximum plant uptake will increase the potential that the crop has sufficient N for both yield and protein. On winter wheat, spring top-dressed N followed by irrigation produced the same yields as fall incorporated N, but had 0.8 to 1.3 points higher protein (*12*). Late-season N can be applied specifically to boost protein. For example, irrigated spring wheat protein increased by 0.5 to 2 points when initial N was optimal for yield and an additional 40 lb N/acre was applied at heading (*FF11*).

Protein increases have been found with late-season N applied anytime between boot and early-milk stages. The average protein increase for the same amount of applied N was about two times higher when N was applied before- or during flowering than after flowering in dryland production (**Figure 5A**). The lower response of post-flowering applications in dryland production is likely because there is low chance of adequate rainfall to push N into the soil and promote N uptake, and less time to convert available N to protein. In a Kansas study, N applied from flowering to two days after flowering on dryland winter wheat increased protein more than any other time (*16*). However, the ability to incorporate fertilizer applied anytime between boot to shortly after flowering with potential rainfall is more important than timing the application exactly at flowering (*20, 21*). The protein change in response to late-season N is generally greater and more reliable under irrigation than dryland production (**Figure 5A and B**) because the N is usually incorporated with irrigation, increasing N uptake.

Use methods to maximize N use efficiency.

Not all of late-season applied N will go to protein. The N can be lost to volatilization, "denitrification" to N_2 gas, leaching, tie-up by soil microbes, weed uptake or directed to plant functions not related to grain protein. Volatilization is most likely the largest loss in Montana in average years, even from surface-applied urea in cold weather conditions (*FF59*).

Although N leached deep into the soil might be reached by wheat roots late in the season to form protein, N leaching should be avoided to benefit crop production, protect groundwater, and slow soil acidification. See *Minimizing Nitrate Leaching from Cropland* for more information.

Foliar applications are least likely to damage the stand as long as rates are low enough to prevent leaf burn. No more than 30 lb N/acre of UAN and 45 lb N/acre of liquid urea should be applied to minimize burn and yield loss (*13*). Greenhouse research has found that only 1 to 16 percent of foliar applied N is actually taken up through the leaf surface (*22, 23*). If possible, applying the N by sprinkler with ½-inch of water would ensure the N is moved into the soil to increase N use efficiency and limit leaf burn. However, if there is risk of scab do not irrigate within five days of flower (*24*).

Adding a surfactant may increase retention of liquid urea on the leaf surface until the fertilizer can be moved into the soil, and therefore improve N recovery and protein response (*23*). However, leaf damage may increase if surfactant is used with higher than 20 lb N/acre of 28-0-0 UAN or when a urease inhibitor (such as Agrotain®) is added with foliar applied urea (*25, 26*).

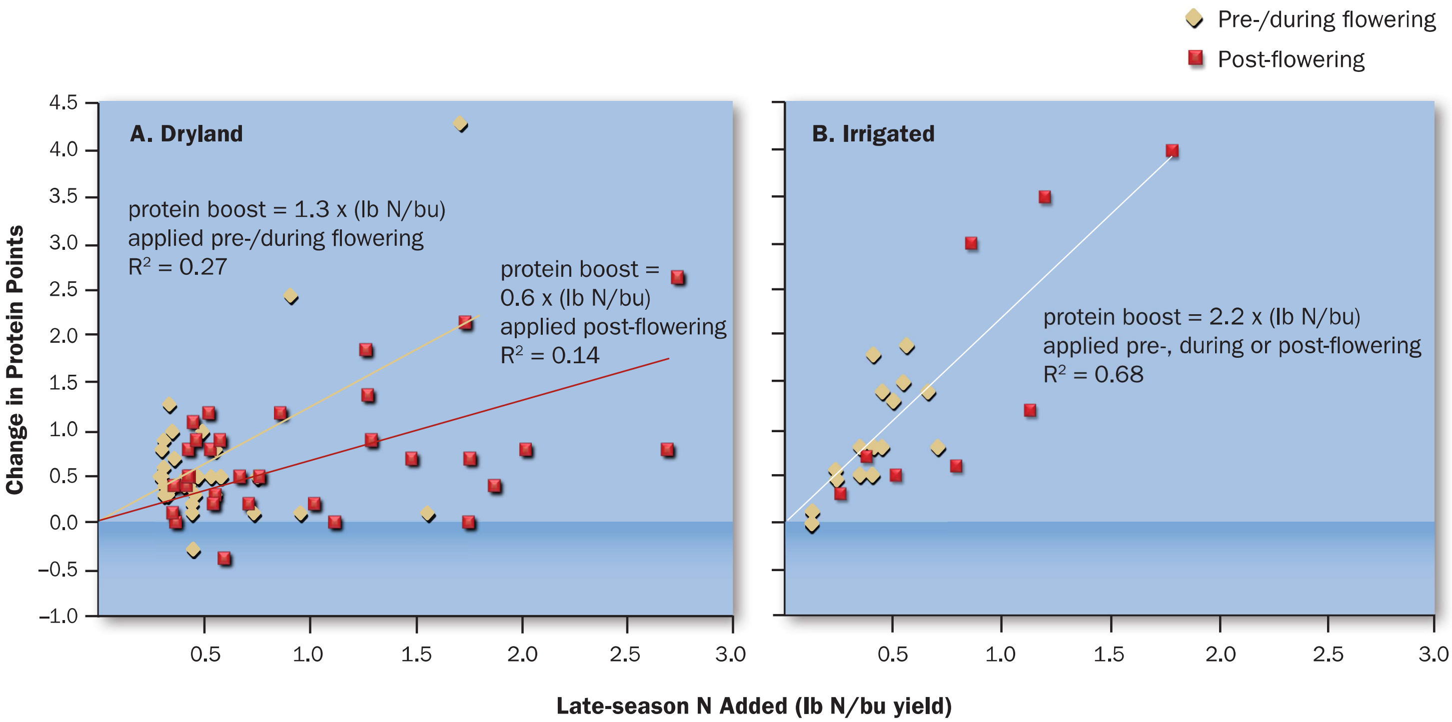

Figure 5. Change in grain protein points in response to N per bushel of yield applied pre-/during flowering or after flowering in A) dryland, and B) irrigated production. (*12* to *19* and *FF11, 23* and *30*).

In dryland production, late-season N application is ineffective if there is insufficient rainfall after application to move the fertilizer into the soil and allow plant uptake of added N; therefore, applying N well before flowering lowers risk, even though it likely lowers the potential grain protein increase. Irrigated systems have more options than dryland systems to apply and/or move fertilizer into the soil.

Nitrogen source.
Wheat protein can increase regardless of N source, including residual N at deeper soil depths or from mineralized N. Nitrogen source should be selected based on cost per pound of N that ends up being available to plants and the convenience of application, balanced by the potential damage to the crop and soil acidification. Manure and legumes in rotation provide N over the growing season. Growing legumes before wheat should boost protein (*FF68*) and profit (*FF76, FF82*). For more information on these N sources please see *Soil Nutrient Management on Organic Grain Farms in Montana*.

Enhanced efficiency fertilizers are another option to provide N later in the growing season. Controlled and slow release fertilizers should have the best chance of boosting protein as a pre-plant application for winter wheat. However, their N release may be too delayed for winter wheat if top-dressed in late winter or early spring (*27*) or for spring wheat in our cool growing conditions. Agrotain® can protect in-season applied urea from volatilization for up to a couple of weeks, while foliar slow release fertilizer has produced mixed results (*28, 29, 30*). See *Enhanced Efficiency Fertilizers* for more information on these specialized products. Manufacturers' claims have not all been substantiated by independent research. We encourage you to find data from local studies on fertilizer products, or conduct your own strip trials (see Ground-truthing fertilizer and manure application rates under 'Web Resources' on page 9) to help assess your options.

Predicting response from late-season N.
Response to late-season N is highly variable and depends on variety response and yield potential, plant N content, N rate and timing and N use efficiency, all of which are overridden by subsequent growing conditions that determine grain protein. In years with average climate, producing average yields, suggested pre-plant N rates are probably sufficient to meet yield and protein requirements (*1*). In high yield years, pre-plant N may be used up by heading and additional N can increase grain protein. Studies in South

Dakota with winter and spring wheat found foliar N applied post-pollination (Feekes = 10.8) increased grain protein 70 percent of the time if yield goal was exceeded, yet only 23 percent of the time when yield potential was not met (*14*).

We encourage producers to do late-season strip trials or N ramps on their farm to calculate their own protein and economic responses to late-season N.

Sulfur

The protein response from foliar application of sulfur (S) has been inconsistent and unpredictable in Montana (*FF30, FF41*) and the addition of 18 lb S/acre as sulfate at seeding increased yield but not grain protein (*31*). However, S helps with N uptake in wheat, especially at higher N rates (*32*), which should increase grain protein. Therefore, if a grower adds late-season N exceeding the requirements for yield and does not get a protein response, there may be an S deficiency. A combination of foliar N (27 lb N/acre) and S (10 lb S/acre) applied at flowering was necessary to obtain protein quantity and quality that was not achieved with N or S applied alone (*33*).

Economics

There is not a set optimal balance between yield and protein for maximum return. Both need to be considered in making management decisions. The decision to apply late-season N to increase protein should be based on the ability to apply N without severely damaging the crop, whether protein discounts are sufficiently high to justify the cost, and the probability of N being taken up and boosting protein. Discounts/premiums and protein response are the most uncertain. The latter is hard to predict especially in dryland conditions, and historical records are not a good predictive tool for discounts.

A pound of N put into protein may have a higher return than a pound of N put into yield when discounts are high. For example, we can compare two harvests with identical N yield (lb N/acre). Using a $4.40 market price and discount of $0.42 per quarter point (*34*), spring wheat yielding 30 bu/acre with 14 percent protein earned $47 more per acre than spring wheat yielding 32 bu/acre with 13 percent protein. However, using the 12-year average discount of $0.10 per quarter point, the spring wheat yielding 30 bu/acre with 14 percent protein only earned $4 per acre more than that yielding 32 bu/acre with 13 percent protein. For more examples of economic analyses of late-season N on irrigated spring wheat, see *FF20*.

It's a fine balancing act to have N available after the boot stage to boost protein with minimal risk of N loss from the system. High N use efficiency is key. Systems including legumes boost protein, lower N fertilizer needs which reduces soil acidification, and reduce risks from annual economic variability (*FF72, FF82*).

Summary

Agronomic practices are available to boost wheat grain protein without sacrificing yield. Select appropriate varieties, know your residual soil N and crop N status, select an appropriate pre-plant N rate, use fertilization practices that minimize N losses, and add N if flag-leaf N is lower than about 4 percent at flowering. This should result in a protein boost, and results in less residual soil nitrate, ensuring less money is lost on unused N fertilizer that could leach out of the root zone and eventually to groundwater. When best of efforts do not increase grain protein, there is the option to sort the grain based on protein content and blend it after harvest to achieve economically optimal average protein.

Acknowledgements

We thank the following for their expertise and time as reviewers of this bulletin:

- Brad Brown - Retired Extension Crop Management Specialist, Parma Research and Extension Center, University of Idaho, Parma, Idaho
- Neil Fehringer - Fehringer Ag Consulting, Billings, Montana
- Dan Picard - Former Pondera County Extension Agent, Conrad, Montana
- Olga Walsh - Associate Professor, Virginia Tech

We also greatly appreciate the many professionals who dug deep to provide details of studies done many years ago.

For more information

These bulletins can be found by title under landresources.montana.edu/soilfertility/publications.html, or by contacting MSU Extension Communications at 406-994-3273 or online at store.msuextension.org/Departments/Publications.aspx.

- *Enhanced Efficiency Fertilizers*, EB0188
- *Minimizing Nitrate Leaching from Cropland*, EB0226
- *Soil Nutrient Management on Organic Grain Farms in Montana*, EB0200

WEB RESOURCES

- *Cropland Soil Acidification* landresources.montana.edu/soilfertility/acidif/index.html
- *Ground-truthing fertilizer and manure application rates* landresources.montana.edu/soilfertility/documents/PDF/PR/GroundTruthingFertilizer.pdf
- *MSU variety selection tool* www.sarc.montana.edu/php/varieties/winter_wheat/
- *Small Grains Nitrogen Economic Calculator* www.msuextension.org/econtools/nitrogen/index.html
- *Soil Sampling* landresources.montana.edu/soilfertility/soil-sampling-methods.html
- *The Soil Scoop: Nitrogen Management for Grain Protein* landresources.montana.edu/soilfertility/soilscoop/

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FERTILIZER FACTS

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